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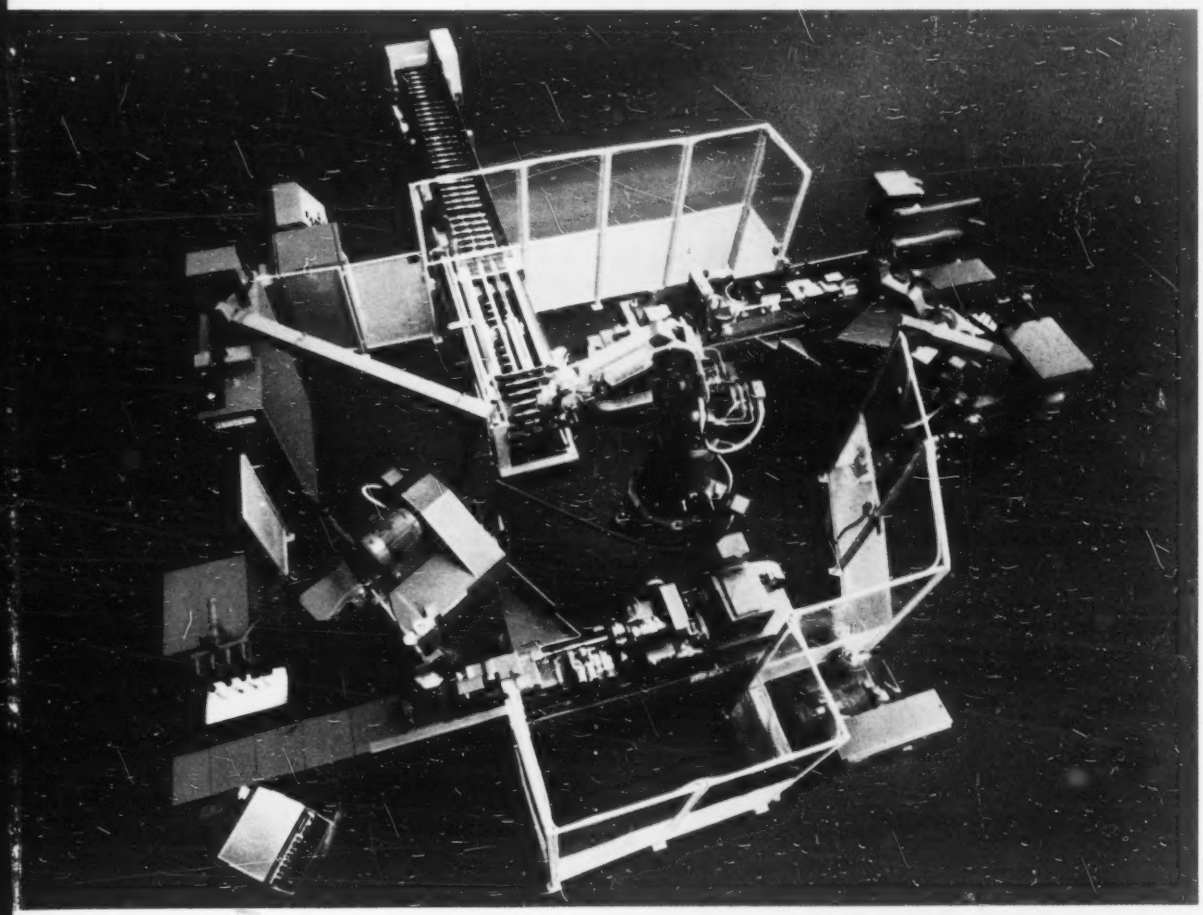

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'Expert Systems' Capture Manufacturing Brainpower

Built-in knowledge handles novel problems and accepts uncertainty in response to requests for information

Michael J. Wilson
Associate Editor

Intelligence. Reasoning. Heuristic judgment. These are some of the terms being applied to artificial intelligence, the subfield of computer science concerned with symbolic reasoning and problem solving.

Artificial intelligence (AI) has been around for 30 years, but the majority of activity has been in university research laboratories addressing theoretical problems. However, recent advancements have made it possible for computer systems to achieve, in many cases, levels of problem solving equal to or better than the best human performance in various disciplines. Recent developments have made it practical to apply artificial intelligence techniques to solve critical problems in the manufacturing industry. Manufacturers are turning to AI vendors to improve their operations.

AI's potential is summed up by Richard E. Morley, director of advanced technology, Gould, Inc., Amherst, NH: "Artificial intelligence represents the edge of the intellectual revolution, which should change our lives at least as much as the industrial revolution. The industrial revolution substituted machines for muscles; artificial intelligence substitutes minds for machines."

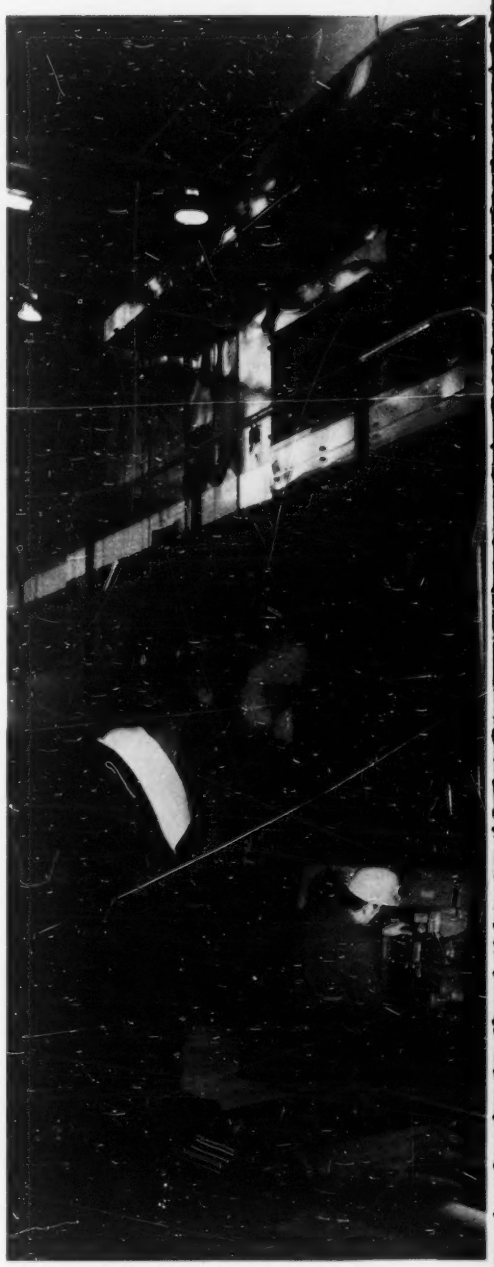
AI as a commercial venture also is in its infancy. The market in 1984 for all AI-based products was $125 million, according to Aim Publications, Inc., Natick, MA, publishers of *Artificial Intelligence Markets* newsletter. Aim projects the market to more than double, to $265 million this year, reach $895 million in 1987 and jump to $4.4 billion in 1990. In 1984 software accounted for 36 percent of revenues and that is expected to grow to 43 percent by 1990.

The impact of AI on the industrial marketplace involves knowledge-based expert systems, robotics, machine vision, speech and natural language processing.

AI appears to be where robotics was five to seven years ago—a high growth area with a bright future supported by venture capital.

Expert Systems

Knowledge-based expert systems are the area where AI made the most progress in the last few years. In the manufacturing industry this includes software programs that emulate the decision-making process of human experts. Expert systems have been successfully applied to equipment diagnosis, inventory control, order entry, planning, design, etc. Expert systems are being developed today that debug automatic assembly lines, troubleshoot electronic circuit problems, schedule job shops and monitor and coordinate FMS systems on a real-time basis. In the future they will advise manage-



ment on strategic planning.

Expert systems concentrate the collective processing power of public and private knowledge on specialized areas, or domains, according to Richard A. Herrod, Ph.D, senior technical staff, Texas Instruments, Inc., Dallas. "This provides expert levels of performance where human experts are either unavailable or not cost effective. Expert systems smooth the transition and serve as a training tool for new personnel when expert personnel retire, transfer or quit."

GE researchers troubleshoot locomotives via the CATS expert system. It displays detailed drawings of various locomotive components during a question/answer troubleshooting procedure. Repair procedures are demonstrated on a video monitor shown at left

Instead of being programmed to follow step-by-step procedures, an expert system is programmed to follow a few general procedures for finding solutions to problems, he explains. "Rules of thumb, models, facts and other knowledge about solving a problem are stored in computer memory. To solve a particular problem the computer utilizes facts provided by the user plus its domain knowledge and general problem solving procedures to find a solution.

"Knowledge used by expert systems is usually encoded in the form of rules," he continues. "Rules contain an antecedent and a consequent. An antecedent typically contains several clauses linked by ANDs and ORs. The consequent contains one or more action phrases that specify what is to be done when the rule 'fires.' A typical rule for an automobile diagnosis might be: IF having trouble starting engine, AND starter can crank engine, AND engine is receiving gasoline, THEN check for ignition problem."

To build an expert system a skilled knowledge engineer interviews domain experts and compiles information from documents, books and manuals to establish a knowledge base. This information is coded into the computer, often in LISP language. A prototype system is built, tested, modified and debugged until it attains expert performance. It is an incremental process. A simple prototype can be built in one year, a medium difficult project takes three to five years and difficult systems take seven to ten. Even then modifications are still made. An expert system is never complete; it can always be improved.

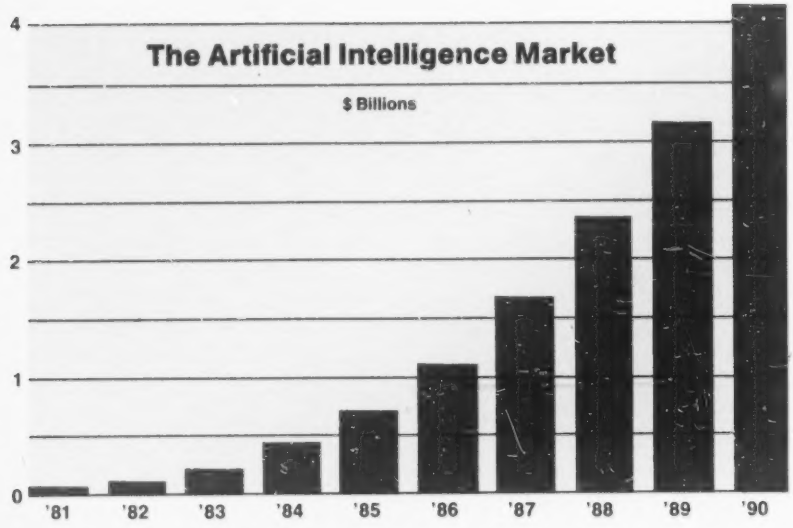
Interest in AI is worldwide. Companies in and the governments of Japan, Britain, France and other European nations are competing with the U.S. for AI leadership. Japan's fifth generation computer project, the so-called "thinking computer," is intended to support inference engines for expert systems targeted to dominate AI and the information industries by the 1990s. Domestically, about 200 to 300 companies are developing AI products. Industrial giants that have created in-house research programs include Gould, IBM, Texas Instruments, Digital Equipment Corp., Litton Industries, Northrop Corp., General Motors Corp. and its subsidiary Hughes Aircraft Corp.

However, most companies view AI as extremely competitive—something they hold close to their vest like they were playing poker for their last nickel. They don't want to reveal what they are doing or how they are doing it for fear of giving away secrets. Following are a few companies involved in AI whose experience varies from prototypes to expert systems. They are among the 150 to 200 with working expert systems or 500 to 1000 prototypes operating in the U.S.

Digital Equipment Corp.

Digital Equipment Corp., Hudson, MA, is a pioneer in industrial AI. The company has 200 people supporting about 50 internal AI productivity projects in manufacturing, diagnostic and service related applications, engineering and finance.

XCON (Expert Configurer) is DEC's oldest AI project and illustrates a classic expert system. It examines all VAX and PDP-11 computer orders ensuring that they have correct and complete configurations. This is an extremely difficult task because a VAX computer configuration is drawn from an infinite variety of combinations of disk drives, power supplies, memory, I/O channels, CPUs, cables,



Source: DM Data Inc., Scottsdale, AZ

cabinets, consoles, etc. FORTRAN and BASIC programs written in the '70s failed to solve this configuration checking problem because they lacked flexibility to handle all combinations.

In 1979 an XCON prototype was developed in conjunction with Carnegie-Mellon University, Pittsburgh, and became operational in 1980 with 750 IF/THEN rules. Today it has 5000 and is still growing. XCON verifies a typical configuration in one to two minutes, performs six times as many functions as a skilled engineer and is 95 percent accurate. In contrast, an engineer takes one to two hours and is only 75 percent accurate.

"We view AI including XCON as an adjunct, a positive addition to our set of software tools," says Arnold Kraft, artificial intelligence marketing specialist. "It is used daily and trusted. The system has paid for itself many times over."

General Electric Co.

General Electric Co., Transportation Systems Business Operation in Erie, PA, a manufacturer of diesel electric locomotives, entered into a joint development program in 1980 with the company's Corporate Research and Development Center in Schenectady, NY. Its objective was to build a stand-alone box to aid locomotive troubleshooting. The system, known as CATS—Computer Aided Troubleshooting—also is used to train employees.

A field test unit is installed at Burlington Northern Railroad and Union Pacific for hands-on use. "It is intended primarily for a new railroad employee, a transferee or a third shift operator without access to a troubleshooting expert," says Robert Herman, manager of technology support. "The concept is to take accumulated knowledge from a locomotive troubleshooting expert and bundle it in a box utilizing the latest computer technology. Conceivably you can build hundreds of these boxes and stretch the knowledge base to troubleshooters on the railroad shop floor."

The system utilizes a DEC (Maynard, MA) PDP 1173 programmed in FORTH, a Winchester disk, a terminal, a printer and a Sony laser disk player with monitor. It began with 400 rules and now has over 1000.

CATS aids troubleshooting like a decision tree by pursuing IF/THEN/ELSE rules, multiple choice or YES/NO questions. It might ask a multiple choice question such as, "DO YOU HAVE (A) A FUEL PROBLEM? (B) COMBUSTION PROBLEM? (C) LUBRICATION PROBLEM? (D) PROBLEM'S ORIGIN UNKNOWN." Selection of A, B, C or D prompts a different set of YES/NO questions: "IS THE ENGINE RUNNING AT FULL SPEED?" or "IS IT ACHIEVING FULL HORSEPOWER?" When the operator is unable to answer such questions, he presses a "help key" which displays on a CRT either a sound movie, a CAD drawing or a photograph, sometimes with audio, to illustrate and respond to the unanswered question.

"It is too new and small to say how many problems are being solved," cautions Herman. "It is not a panacea. This is a long term development progressing in a methodical fashion that we see more as evolutionary than revolutionary. What we learn from field testing will be incorporated into the next generation."

Westinghouse Electric Corp.

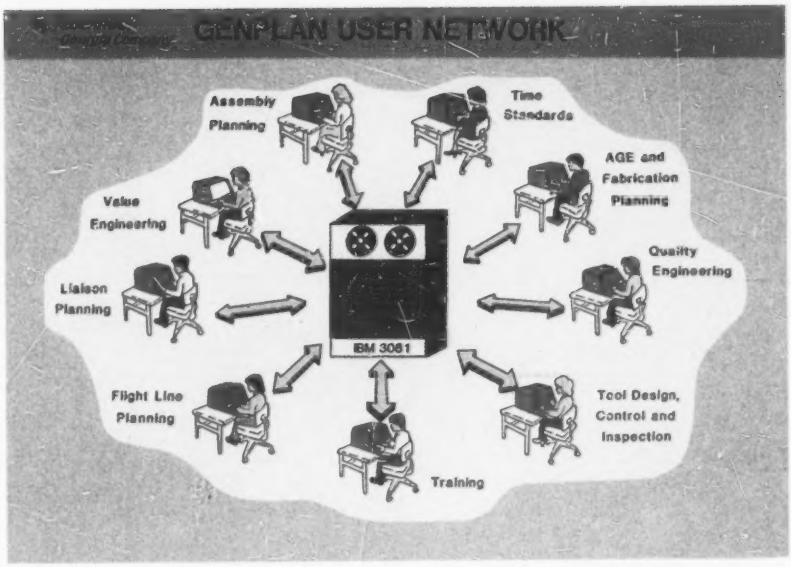
Westinghouse Electric Corp., Pittsburgh, recently demonstrated an expert system called ISIS—Intelligence Scheduling Information System—at the company's turbine plant in Winston-Salem, NC. The Carnegie-Mellon University-developed program combines AI with shop floor programming utilizing constraint directed reasoning. The system scheduled manufacturing of various length and shape turbines on about 25 machine tools for the demonstration.

"Scheduling is the premier problem in manufacturing," claims Peter Papas, manager-computer integration and software systems. "ISIS optimizes scheduling. It helps the changing manufacturing environment adjust to increased throughput, minimize work-in-process inventory, maximize machine utilization and react

when materials don't arrive or operators aren't at their station."

The system also can be used in a simulation mode to determine if an incoming order is deliverable on time. After order entry the system might relate, for example, that to meet the delivery schedule, turning machine #3 requires a second shift for two days or perhaps the lack of semifinished material inventory will delay manufacturing operations.

The Westinghouse demonstration, performed under simulated conditions, was the first step in implementing this technology on the shop floor. The company is now executing the second phase of installing a LISP machine prototype consisting of about five machine tools at a smaller shop by year's end. Lessons learned from the prototype will be retrofitted to the turbine plant.



GenPlan user network interfaces with many planning and engineering phases of manufacturing (above). Joseph Tulkoff, director of manufacturing technology, Lockheed-Georgia Co., utilizes GenPlan to implement process plans for the C5B cargo airplane

Lockheed-Georgia Co.

Lockheed-Georgia Co., a division of Lockheed Corp., Marietta, GA, has developed a generative process planning system called GenPlan. The system creates in response to a group technology characterization code the initial plan for the manufacture of discrete aircraft parts, subassemblies and major assemblies.

It is a knowledge-based expert system established in 1978 that represents several thousand man-years of best factory practice and replaces a manual system. It allows a process engineer to create the documentation that identifies the optimum sequence of manufacturing operations. It details all necessary raw materials, tools, machines and processes and determines a time standard for each step.

GenPlan's knowledge base includes machining requirements, specifications, material requirements, etc. The system serves process planners, time standard engineers, quality control engineers and producibility engineers via 130 CRTs networked to an IBM 3083.

"The system provides many benefits," says Joseph Tulkoff, director of manufacturing technology. "For example, it saves 50 to 60 percent of process planning labor. Time standards are now consistent and accurate because humans have been eliminated from their calculations. Leadtime is reduced up to 75 percent. It eliminates key punching and verification. Furthermore, it has automatic control of configuration. That is, each process plan has a unique change code number which prevents two planners from changing the same plan."

Benefits on the factory floor include uniform flow of parts. There are no missing or redundant operations and it saves material. For example, chucking a part on a lathe requires a specific length of stock for gripping by a collet or chuck. Human process planners vary considerably in this determination. But GenPlan always selects the right amount without variation.

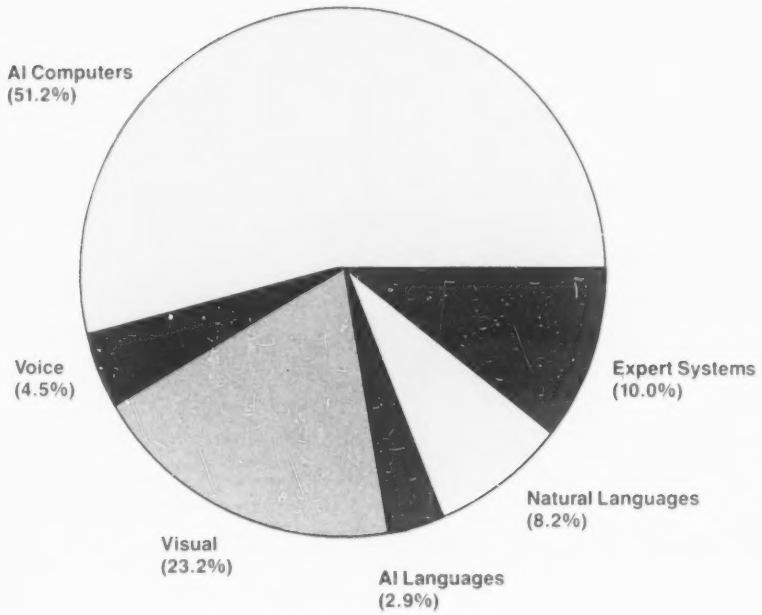
Sandvik Coromant Co.

Sandvik Coromant Co., Fair Lawn, NJ, also has a process planning system and simulation program that includes some aspects of tool management. The system, known as SPOCK—Sandvik Productivity Optimization Cutting Knowledge — is an expert system based on 15 years of tooling and machine test data acquired worldwide. The system has been tested at General Motors Technical Center, Warren, MI, for the past year and is now being tested at manufacturing plants.

SPOCK is a software package written in BASIC A language that operates on an IBM XT or AT personal computer. It utilizes algorithms and a YES/NO menu format.

SPOCK's primary purpose is to optimize tooling data. The user selects the cutting tool insert grade and the program calculates speeds and feeds, tool life, cycle time—both machining and non-machining time—and provides a total time for one piece or a batch. In addition, it calculates the cost of

The Artificial Intelligence Market Product Areas — 1985



Source: DM Data Inc., Scottsdale, AZ

the entire operation. Total part cost is given if multiple machines are used. Costs are divided into labor, overhead, depreciation, tooling, etc. Times and costs of alternate machining methods are simulated on a bar graph providing a cost comparison.

An operator can input a specified surface finish requirement for a particular part and the program automatically calculates speeds and the best tool life under minimum cost conditions. Or, the operator picks the speed and the program predicts tool life. If a production increase is desired, the system reveals the required speeds and feeds.

"SPOCK will optimize constraints and cut cycle time by 30 percent," predicts Bertil Colding, vice president-advanced systems products. "It can reduce a process plan 80 percent and increase the output of process planners several times."

Gulf Oil Corp.

GREASE is an expert system that aids in the choice or formulation of a cutting fluid for a machining operation. It is currently under development at the Intelligent Systems Laboratory at Carnegie-Mellon University in cooperation with Gulf Oil Corp., a subsidiary of Chevron, San Francisco. The goal is to select a cutting fluid that will make a machining operation as economical as possible through trade-offs between the price of a cutting fluid and tool life.

GREASE performs a wide variety of tasks and handles various kinds of input. For instance, it will select the cutting fluid that will make machining operations most economical given a mix of metals being machined, a variety of machining operations, depths of cuts, speeds and other information. It also can diagnose difficulties with a cutting fluid currently in use. For example, it may reveal poor tool life caused by an excessive heat build-up during machining. A lower viscosity cutting fluid with better cooling properties may be prescribed. If no existing cutting fluid has the properties required for satisfactory performance, then GREASE creates a blend of cutting fluids that most closely matches the desired properties. In addition, it can explain and justify the selection of a special cutting fluid.

Although the potential for AI is immense, the technology is still developing. Expert system development is costly and companies involved in expert systems sometimes experience disillusionment after initial high expectations. A wide range of LISP dialects will not run on a machine that supports another dialect. Expert systems can be unpredictable or act ineptly at the border of their knowledge. The availability of skilled computer scientists experienced in expert systems is also holding back development processes.

While there are cautions, potential rewards are huge. As the technology matures reliability will improve and costs will fall. Its utilization on the factory floor will proliferate and increase factory effectiveness. It will preserve know-how and apply it in an optimum manner. It truly will be a versatile tool in the factory-of-the-future. ■

Six Steps In Making an Expert System

(1) Pick a problem

(2) Extract knowledge from an expert

(3) Write rules in a program

(4) Test rules on small cases

(5) Go into live test

(6) Iterate into commercial use

* *Courtesy Gould Inc., Amherst, NH*